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RESEARCH ARTICLE

UNCERTAINTY CALCULATIONS OF PRESSURE SENSITIVITY OF ONE INCH MICROPHONES USING PRESSURE FIELD METHOD AT NIS

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ABSTRACT

Primary calibration method is used by relatively few laboratories such as national calibration laboratories and few large automotive, space or governmental organizations which work at high technological level. The National Metrology Institute of Egypt (NIS) has developed a pressure calibration system that used for calibration of pressure sensitivities. In this study, we estimate the uncertainty of unknown one inch condenser microphone using two known references one inch condenser microphones according to international standard. IEC 61094-2009 which gives more information's and details on the uncertainty calculations. In this method a wide frequency range with a high accuracy and repeatability were achieved.

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INTRODUCTION

To accommodate the wide variety of microphone types, characteristics and applications, various calibration procedures greatly differ in complexity, uncertainty and the labor and equipment costs required to realize given frequency ranges and accuracies. So the National Metrology Institute of Egypt (NIS) has developed a pressure reciprocity calibration system that used for calibration of pressure sensitivities. Pressure field reciprocity calibration is considered the most easy and less costly method. By this method a high accuracy and repeatability will be reached and a wide frequency range will be covered. Reciprocity calibration can be performed by pressure-field calibrations in accordance with the international standards IEC61094-2(2009) (IEC, 2009). The reciprocal nature of capacitor microphones led to the development of a new means of absolute calibration of microphones (Cook, 1941). Since then, the reciprocity technique has become the accepted method for realizing primary standards for sound pressure, through the calibration of laboratory standard (LS) microphones.

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The International electro technical committee IEC had standardized the method for calibration of the pressure sensitivity of LS microphones and today the principal requirements are specified in IEC 61094-2 (2009). Since then many different reciprocity calibration systems have been developed by various national measurement institutes organizations, each complying with IEC 61094-2. In the National Institute for Standards (NIS), the pressure calibration system has been improved to realize more precise calibration of pressure sensitivities. In this study, we analyzed measurement uncertainty of pressure sensitivities calibrated at NIS. Analysis was based on an international document, "Guide to the Expression of Uncertainty in Measurement" (International organization for standard, 1993).

MATERIALS AND METHODS

Pressure Calibration Method by Using Reciprocity Technique

Pressure reciprocity calibration of microphones is generally carried out by means of three reciprocal microphones. Type 9699 applies the most common way, the three microphone method.

The method is based on determination of the electrical and the acoustic transfer impedance of pairs of microphone that are acoustically coupled together. One of the microphones acts as a source and creates a sound pressure in the cavity of an acoustic coupler, while the other one responds to this pressure and generates a corresponding electrical output voltage, see Fig.1.

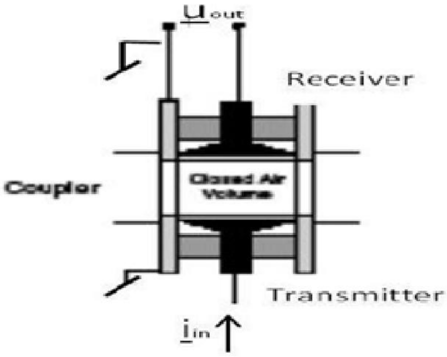


Fig. 1.Type 9699 principle of transmitter current measurement

The IEC standard defines the electrical transfer impedance for a system of two acoustically coupled microphones as the quotient of the open circuit voltage of the receiver microphone and the input current through the electrical terminals of the transmitter microphone according to the following equation.

$$Z_{e,xy} = \frac{u_{out,xy}}{i_{in,xy}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where U_{out} is the output voltage and i_{in} is the input voltage. The acoustic transfer impedance of the coupled microphone pair is defined as the quotient of the sound pressure acting on the diaphragm of the receiver microphone and the short-circuit volume velocity produced by the transmitter microphone. According to the reciprocity theory and the description given in IEC standard, the product of the sensitivities of the two microphones equals the quotient of the electrical transfer impedance and the acoustic transfer impedance; see Equation 2. The electric transfer impedance is measured, while the acoustic transfer impedance is worked out from the mechanical dimensions of the coupler, the properties of the gas enclosed in the cavity and the acoustic impedance of the microphone diaphragms. According to the reciprocity theory and the description given in IEC standard, the product of the sensitivities of the two microphones equals the quotient of the electrical transfer impedance and the acoustic transfer impedance; see Equation 2. The electric transfer impedance is measured, while the acoustic transfer impedance is worked out from the mechanical dimensions of the coupler, the properties of the gas enclosed in the cavity and the acoustic impedance of the microphone diaphragms.

$$M_{px}.M_{py} = \frac{Z_{e,xy}}{Z_{a,xy}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

M_{px} is the sensitivity of microphone x.

Reciprocity calibration with Type 9699 is performed with three microphones (1), (2) and (3). They can be combined to form three different pairs (1) and (2), (1) and (3), (2) and (3). The sensitivity results are given in terms of modulus (V/Pa) and phase (degrees) as the system Type 9699 determines the complex values of the electrical and the acoustic transfer impedance.

$$M_{p_1}.M_{p_2} = \frac{Z_{e,12}}{Z_{a12}}$$

$$M_{p.1}.M_{p.3} = \frac{Z_{e,13}}{Z_{a_{13}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$M_{p.2}.M_{p.3} = \frac{Z_{e,23}}{Z_{a_{23}}}$$

Equation 4 below gives the solution for microphone (1).

$$M_{p1} = \left(\frac{Z_{e12}.Z_{e13}}{Z_{e,23}} \cdot \frac{Z_{a23}}{Z_{a,12}.Z_{a13}} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Microphone Couplers

Type 9699 includes a set of two of plane-wave couplers of different length for each type of Laboratory Standard Microphone, LS1. The shorter coupler is intended for calibration from the lowest to the highest frequencies, while the longer one works from the low to medium high frequencies.

Electrical Transfer Impedance

Today most National Metrology Institutes aim for calibrating their national standard microphones with a repeatability of the order 0.01 dB to 0.02 dB and with an uncertainty that is typically as low as 0.1 dB to 0.06 dB (k=2) in the best frequency range. The instrumentation and the method for the measurement of the electrical transfer function, i.e. the voltage ratio are therefore selected for measuring with an uncertainty that is about 10 times less than the above numbers (Fig 2).

Fig. 2. reciprocity system

The generator of the system that is integrated in the pulse multi-analyzer supplies the signal that drives the transmitter microphone.

The dedicated reciprocity apparatus has two measurement channels with gain, one for the receiver microphone output voltage and one for the voltage that represent the transmitter current. The signals are essentially equally amplified in steps of 10 dB to fit into the interval, 0.05 V to 2 V at the inputs of the two-channel Pulse analyzer that performs the voltage measurements. To obtain accurate and reliable calibration results, practically any set or triad of microphone is calibrated with two or more couplers. The corresponding sets of measurement data are all stored in the same measurement data file together with the identification data for the microphones and the applied couplers. After finishing the measurements, the sensitivity of the microphones may be calculated by applying the MP.exe program that belongs to Type 9699 and works in accordance with the international microphone calibration standard IEC 61094-2.

Microphone Parameters

The microphones parameters of LS1 of serial numbers 2796471, 2796472 and the unknown microphone are shown in the following Table (2).

Table 2. Microphone parameters for LS1 microphones

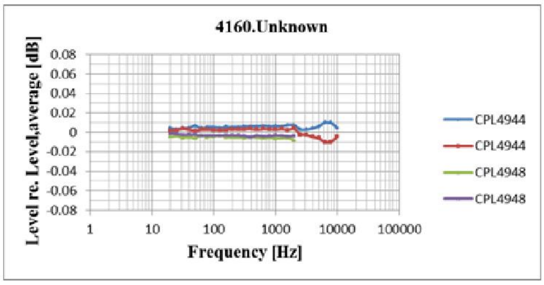
Microphone type	4160	4160	4160
Microphone serial number	2796471	2796472	(Unknown)
Front cavity depth (mm)	1.953	1.955	1.943
Front volume (mm^3)	538.0	537.8	535.8
Resonance frequency(kHz)	8.2	8.2	8.2

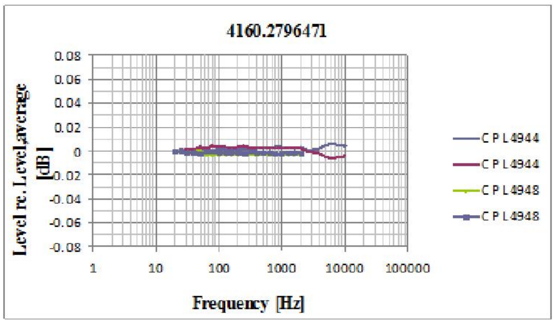
RESULTS

The present procedure for calibration makes a practical compromise between applied time and uncertainty of the results. The procedure includes two couplers for fitting of microphone volume only. This fitting is effective for lowering the uncertainties at low and medium frequencies, say up to 3 kHz and 7 kHz for LS1. The procedure includes four calibrations of the three participating microphones (1, 2 and 3). They are performed with plane-wave couplers of different length and with interchange of the three microphones between the transmitter and receiver positions in the setup.

After finishing the measurements and sensitivity calculations, the results should be separately evaluated for each of the three microphones. If systematic deviations occur between the results of the two couplers for a microphone, its front and equivalent volume should be modified. The evaluation shall be based on the results within the frequency interval 250 Hz – 1000 Hz. In principle, volume fitting of a specific microphone should only be made once, but due to the occurrence of disturbing random errors, it is recommended to check the fitting after some few series of calibration.

The new evaluation and possible re-adjustment of the volume should be based on a larger group of results. Table (3) shows the pressure sensitivities for the three microphones at different frequencies ranging from 20 Hz up to 10 KHz. The results for the two known microphones and the unknown microphone are shown in Figure (3).





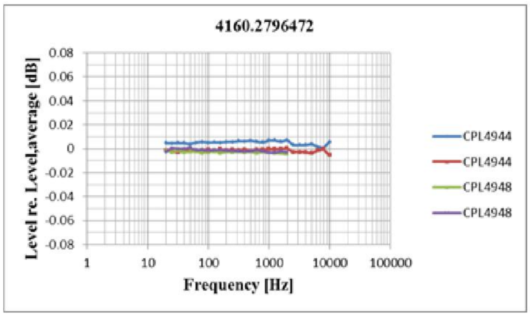


Fig. 3. Shows the calibration result obtained for microphones type 4160 serial numbers unknown (top), 2796471 (middle)and 2796472(bottom) using two couplers CPL4944 and CPP4948

This figure showed that, the comparison of microphone sensitivity as measured with the two systems with a long coupler (20Hz to 7kHz) and with a short coupler (20Hz to 10kHz).
There are many factors that influence the resulting uncertainty of microphone pressure reciprocity calibration; some of them are listed here:

- The instruments and accessories of the reciprocity calibration system Type 9699.
- The periodical calibration, verification and maintenance of these and other necessary instruments
- The types of microphone to be calibrated
- The physical milieu of the calibration laboratory
- The experience of the laboratory staff
- The applied procedure

The International Standard IEC61094-2 gives guidelines for calculation of the uncertainty of microphone sensitivity obtained by pressure reciprocity calibration. It states that, the principles of the GUM document (Guide to the expression of uncertainties in measurement) should be followed and it proposes a calculation method that overcomes difficulties caused by the complex mathematical expressions and by the high number of parameters influencing the resulting uncertainty.

Table 3. values for microphone pressure sensitivities at both measurement and reference conditions for the three microphones

Frequency Hz	4160 (unknown) Level [dB re. 1V/Pa]		4160 no 2796471 Level [dB re. 1V/Pa]		4160 no 2796472 Level [dB re. 1V/Pa]	
	Meas.Cond.	Std. Cond.	Meas.Cond.	Std. Cond.	Meas.Cond.	Std. Cond.
19.95	-26.93	-26.93	-27.03	-27.03	-26.95	-26.95
25.12	-26.94	-26.94	-27.05	-27.05	-26.97	-26.97
31.62	-26.96	-26.96	-27.07	-27.07	-27.00	-26.99
39.81	-26.98	-26.98	-27.09	-27.09	-27.02	-27.01
50.12	-27.00	-27.00	-27.10	-27.10	-27.03	-27.03
63.10	-27.02	-27.01	-27.12	-27.12	-27.05	-27.05
79.43	-27.03	-27.03	-27.13	-27.13	-27.06	-27.06
100.00	-27.04	-27.04	-27.15	-27.14	-27.08	-27.07
125.89	-27.05	-27.05	-27.16	-27.15	-27.09	-27.08
158.49	-27.06	-27.06	-27.17	-27.16	-27.10	-27.09
199.53	-27.07	-27.06	-27.17	-27.17	-27.10	-27.10
251.19	-27.07	-27.07	-27.18	-27.18	-27.11	-27.11
316.23	-27.08	-27.08	-27.18	-27.18	-27.12	-27.11
398.11	-27.08	-27.08	-27.19	-27.18	-27.12	-27.12
501.19	-27.08	-27.08	-27.19	-27.18	-27.12	-27.12
630.96	-27.08	-27.08	-27.19	-27.18	-27.12	-27.11
794.33	-27.07	-27.07	-27.18	-27.17	-27.11	-27.11
1000.00	-27.06	-27.06	-27.16	-27.16	-27.10	-27.09
1258.92	-27.04	-27.03	-27.14	-27.13	-27.07	-27.06
1584.89	-27.00	-26.99	-27.09	-27.09	-27.03	-27.02
1995.26	-26.93	-26.93	-27.02	-27.02	-26.96	-26.95
2511.89	-26.83	-26.82	-26.92	-26.91	-26.85	-26.84
3162.28	-26.69	-26.68	-26.77	-26.75	-26.70	-26.68
3981.07	-26.50	-26.49	-26.56	-26.55	-26.49	-26.47
5011.87	-26.32	-26.29	-26.36	-26.33	-26.28	-26.25
6309.57	-26.33	-26.30	-26.39	-26.36	-26.29	-26.25
7943.28	-27.16	-27.13	-27.31	-27.28	-27.16	-27.14
10000.00	-29.75	-29.75	-30.09	-30.10	-29.88	-29.88

According to the standard IEC61094-2 (2009) the final result should be presented as expanded uncertainty valid for a coverage factor 2. The described uncertainty budget is worked out in accordance with these proposals and requirements.

Table 4. values of Uncertainty microphone pressure sensitivities at both measurement and reference conditions for the three microphones.

Frequency (Hz)	Expanded Uncertainty (k=2)
19.95	0.06
25.12	0.06
31.62	0.06
39.81	0.06
50.12	0.06
63.10	0.05
79.43	0.05
100.00	0.05
125.89	0.05
158.49	0.05
199.53	0.05
251.19	0.05
316.23	0.05
398.11	0.05
501.19	0.05
630.96	0.05
794.33	0.05
1000.00	0.05
1258.90	0.05
1584.90	0.05
1995.30	0.05
2511.90	0.05
3162.30	0.05
3981.10	0.06
5011.90	0.07
6309.60	0.08
7943.30	0.09
10000.00	0.15

The IEC standard contains a list of 35 parameters that contribute to the uncertainty of the microphone sensitivity. All parameters are listed in the budget with data for calculation of their influence on the uncertainty. The combined uncertainty of the microphone sensitivity result is a function of frequency. It is calculated by using the following equation:

$$U_{Mp}(f)= [U^2_{MpP1}(f)+ U^2_{MpP2}(f)+ U^2_{MpP3}(f)+\ldots\ldots+ U^2_{MpP(n-1)}(f)+ U^2_{MpP(n)}(f)]^{1/2} \quad \ldots\ldots\ldots\ldots (5)$$

Where;

$U_{Mp}(f)$: is the uncertainty of the microphone sensitivity result (Mp).

$U_{MPP1}(f)$: is the sensitivity Uncertainty Contribution of Input Parameter"Pi".

DISCUSSION AND CONCLUSION

From Table (3), it was clear that the sensitivity of a measurement microphone expressed in decibels referring to one Volt per Pascal (dB re 1 V/Pa). The term "sensitivity", generally means the sensitivity at the reference frequency, which is most often 250 Hz, but in some cases this may be 1000 Hz. The magnitude of the frequency response characteristic represents the ratio between the sensitivity at a given frequency and that of the reference frequency. This ratio is generally expressed in dB. The sensitivity may be used for ranking microphones with respect to their ability to measure low and high sound pressure levels.

The higher the sensitivity, the lower the sound pressure levels found that may be measured and conversely. The sensitivity of the unknown microphone is equal to 44.31 mV/Pa. Figure (3) showed that, the deviation of the pressure sensitivity between short coupler 4944 and long coupler 4948 found within the order of magnitude of 0.01. However deviations are observed at low frequencies. From the calculations of uncertainty and Table 4 it was found that, the uncertainty of unknown microphone is ranging from 0.05 up to 0.15 and it's a good value for the one inch microphone. This study analyzed the uncertainty of pressure sensitivities for unknown microphone B&K types 4160.

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